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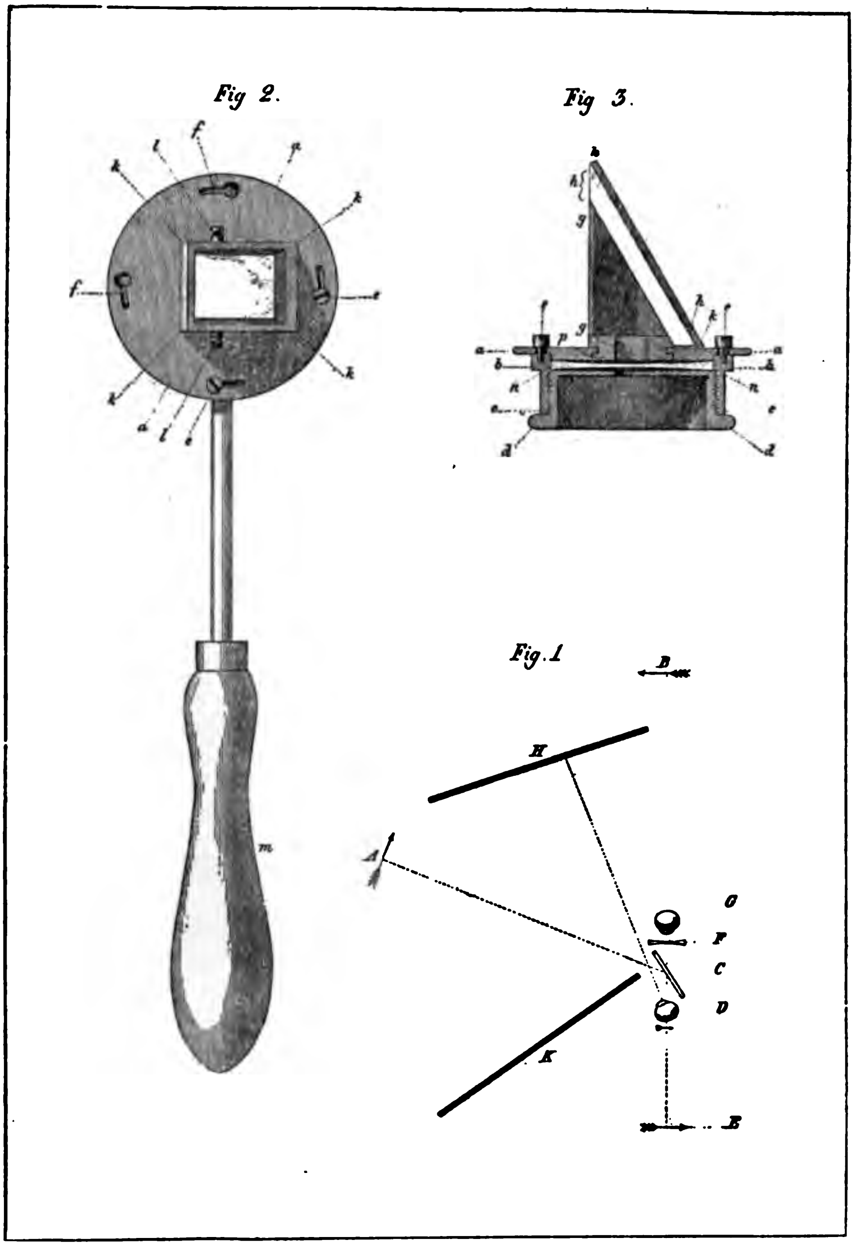
HELMHOLTZ'S DESCRIPTION
OF AN
OPHTHALMOSCOPE

T. H. SHASTID, M. D., F. A. C, S.

With

The Translator's Compliments

R L Wilbur.



[Photographic Reproduction (Actual Size) of the Original Illustration in Helmholtz's "*Beschreibung eines Augenspiegels.*"]

THE DESCRIPTION
OF AN
OPHTHALMOSCOPE

BEING AN ENGLISH TRANSLATION OF
Von HELMHOLTZ'S
"Beschreibung eines Augenspiegels"
(BERLIN, 1851)

BY
Thomas Hall Shastid, A.B., A.M., M.D., LL.B., F.A.C.S.
SUPERIOR, WISCONSIN

And the first translation of this classic into any language

Chicago
CLEVELAND PRESS
1916
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Dedication

It is fitting that this, the first translation into any language of
Helmholtz's *"Beschreibung eines Augenspiegels,"*
should be inscribed to

Dr. Casey A. Wood

Ophthalmologist and almost universal scholar, who has contributed so much to our knowledge of the visual apparatus, and who, in addition, has so indefatigably gathered together and preserved (as in the *American Encyclopedia of Ophthalmology* and works of a similar character) the comprehensive literature of our subject. Because of a friendship lasting now these many years, he consents to waive the imperfections of my rendering, and to accept this very slight performance—which is offered merely as a little token of a high regard. May the fraternal reader be as lenient toward those imperfections as is he, and—I may add—as appreciative (for many are not) of the timeless, the deathless character of the little document which I have had the temerity to try to translate. —T. H. S.

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DESCRIPTION

OF AN

OPHTHALMOSCOPE

FOR THE INVESTIGATION
OF THE RETINA IN THE LIVING EYE

BY

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BERLIN
THE A. FÖRSTNER PUBLISHING HOUSE
(P. JEANRENAUD)
1851

[A translation of von Helmholtz's title-page, treated typographically as nearly like the original as possible.]

THE OPHTHALMOSCOPE

The present treatise contains the description of an optical instrument, by which it is possible in the living to see and recognize exactly the retina itself and the images of luminous objects which are cast upon it.*

---

* Even the ancients, as a matter of course, had noticed that the eyes of certain animals are brilliant in the dark. Thus Pliny (Book XI, Chap. 55): "The eyes of animals that see at night in the dark, cats for example, are shining and radiant, so much so that we cannot bear to gaze upon them; those of the she-goat, too, and the wolf are resplendent, and emit a light like fire." Pliny did not, however, attempt to explain the phenomenon.

In 1704, Jean Méry, of Paris, performed his famous experiment with a cat. Having immersed the animal in water, he first observed that the pupil dilated (as a result of suspended respiration) and then he beheld in all its glory the fundus of the animal's eye—the entrance of the optic nerve and all the colors and vessels of the choroid. Méry understood quite well enough that something more than mere pupillary dilatation was necessary to account for the possibility of observing the fundus of the eye when the eye was under water. His explanation, however, of the "something more" was wholly erroneous. He believed, that is to say, that the view of the fundus was rendered possible by the water's filling up a multitude of tiny "unevennesses" on the anterior surface of the cornea. Five years later, de la Hire stepped forward with the correct explanation. According to him, the water obviated the refraction of light by the cornea, so that all rays leaving a given point upon the fundus emerged from the eye not as parallel, but as divergent, rays. De la Hire also observed, incidentally, that the disturbing light-reflexes proceeding from a cornea *in aero* are done away with by the water.

In 1796 Fermin observed a certain luminosity in the pupils of an Ethiopian albino. In 1816 Scarpa remarked upon a similar phenomenon in a certain disease of the fundus, and, one year later, Beer described the same condition fully, inventing therefor the expression "amaurotic cat's eye"—a term which is still in use. In 1836 Hasenstein first produced a factitious luminosity by compressing the eyeball backward—making the eye, in fact, artificially hypermetropic. In 1847 Babbage, an English mathematician, exhibited to Wharton Jones, the distinguished London oculist, the model of an instrument invented by him for the purpose of examining the interior of the eye. It consisted of a small plane glass mirror, from which a portion of the silvering had been removed. This device, however, was first made known to the world in 1854, by Wharton Jones (*Brit. and For. Medico-Chir. Review*, Oct., 1854). The services of Brücke (in 1845, published in 1847) and of Cumming (in 1846) are adverted to herein by Helmholtz.

The earliest reception of the ophthalmoscope is decidedly interesting. Thus, to quote from Koenigsberger, "*Hermann von Helmholtz.*" (1906) p. 74: "The ophthalmoscope was, however, some time in making its way, on account of the mathematical and physical knowledge presupposed by the '*Description of an Ophthalmoscope for the Investigation of the Retina in the Living Eye,*' published in the autumn of 1851, and people were at first very shy of employing it. One distinguished surgical colleague told Helmholtz he should never use the instrument—it would be too dangerous to admit the naked light into a diseased eye; another was of opinion that the mirror might be of service to oculists with defective eyesight—he himself had good eyes and wanted none of it."—(T. H. S.)

The instrument has, for this purpose, two different problems to solve. First, everything which we can see of the background of the uninjured eye appears to us absolutely dark. The cause of this lies, as I will show, in the light-refracting media of the eye, which, under ordinary circumstances, hinder us from seeing illuminated parts of the retina behind the pupil. Therefore, the first question is to discover a means of illumination whereby exactly that portion of the retina on which we gaze through the pupil may be adequately lighted. Secondly, we view the background of the eye only through the light-refracting media. These, however, cast images of the retinal objects, which, in general, do not lie for the observer within the limits of plain vision. We need, therefore, together with a proper procedure for illumination, also further optical expedients which will render possible for the observing eye a correct accommodation for the objects which it should see.

I. ILLUMINATION.

In order to be able to find the essential conditions for the method of illumination, we must first of all make clear to ourselves why, as a rule, the ground of the eye behind the pupil appears to us to be of so deep a black.

The cause of this is not the condition of the pigment of the chorioidea; for, if the pigment layer absorbed the light which falls upon it even more completely than any other known black substance, still, there lie before the chorioidea parts which can reflect a quantity of light sufficient to render them visible. That is true, first of all, of the substance of the retina, which, to be sure, in the recent condition, is very transparent, and marks itself off but little against the dark pigmentary background; to a much higher degree, however, it is true of the blood-vessels of this membrane, whose tiny stems carry blood enough to exhibit a strongly red hue. Finally, there appears, even in the fundus of the eye, a shining white spot, namely, the place of entrance of the optic nerve, on which no pigment at all lies, and which, therefore, reflects all the light that falls upon it. And yet we observe, under ordinary circumstances, behind the pupil of the living eye, not the slightest trace of the red color of the blood, nor of the white color of the optic nerve.

It can be shown much better by a simple experiment, that not the color of the background, but only the refraction of the light in the ocular media, is the cause of the deep blackening of the pupil. Let one take any kind of small camera obscura well blackened within, and let him bring to the place where the picture is produced an opaque white card, for example one from thick white drawing-paper. Among other kinds of camera may be employed the ocular tubes of most microscopes, after the ocular glass has been removed therefrom, and the collective glass has been inserted. These tubes are, as a rule, precisely as long as the focal distance of the collective glass. If one sets them with the end which contains the ocular upward upon the white card, then they form a camera obscura of the kind we need. There are thrown, in this case, very bright images of the surrounding illuminated objects, on the white card, and still the interior of the instrument, when one looks into the lens in any desired direction, appears absolutely black. We have here a *fac simile* of the eye, where cornea and crystalline lens are substituted by the objective lens of the camera, and the retina by a clear white paper surface, but there occurs apparently the same complete darkness of the internal space as in the eye, as long as the paper surface lies precisely at the spot where the tiny images of external objects are produced. If one takes away the convex glass, or if one materially alters its distance from the paper surface, there appears to the beholder at once the clear white surface of the paper.

How, now, can the refraction of the light produce the phenomenon described? Let us consider the course which the rays of light must take, according to the physical laws of the refraction of light in the eye.

Let light fall from a luminous point upon a fittingly adapted eye, concerning which we assume that it is formed with absolute accuracy, that is, that all the incident rays from the point in question concentre upon a single point of the retina. Of the light which, by the ocular media, is caused to converge upon this membrane, the greater part is absorbed by the black pigment, while the smaller is reflected partly by the nerve elements and blood-vessels, partly by the layer of rod-shaped corpuscles. That which is thrown back by the latter structures, passes, as E. Brücke has shown, back out through the pupil, without becoming scattered to any other portion of the wall of the eye. In this way is avoided the spreading of perceptible quantities of dispersed light within the eye. The reflected rays, which, from the point of convergence on the retina, pass back out divergently to the refracting surfaces of the eye, follow then precisely the same path, in a reverse direction, by which the incident rays of the luminous point converged from the refracting surfaces of the eye until they reached the retina. From this it follows that the returning rays, even after they have passed clear through the refractive media and out of the eye, must coincide completely with the incident rays, must therefore finally all betake themselves to the original luminous point.

For, when two rays, which pass through several simply refracting media in a reverse direction, coincide in one of the same [media] they must do the same in all [the media]. On the limiting surfaces of the medium, that is to say, within which they coincide, the angle of incidence of the outcoming rays is identical with the angle of refraction of those which are entering. As, now, according to the laws of refraction, the proportion of the sine between the angle of incidence and the angle of refraction of the former, is precisely as large as that between the angle of refraction and the angle of incidence of the latter, so must also, on the other side of the refracting surface, the angle of refraction of the outcoming and the angle of incidence of the ingoing, rays, be equal. As, at the same time, all these rays lie in one plane, the plane of refraction, it follows that they also fall into one another [coincide] in the second medium. In like manner it follows further for the third, fourth medium, and so on.

Let us apply that to the case where any given system of refracting surfaces produces an exact image of the luminous point *a* at the point *b*, that is, where all the rays which proceed from *a* unite again in *b*, then follows the well known fact that in this case, always, *a* will be the image of *b*, if the latter sends out rays. Exactly upon the same paths, that is to say, on which rays from *a* proceed to *b*, they may also return from *b* to *a*. If now *a* is a luminous point outside the eye, and *b* its image, a point on the retina, then the ocular media will concentrate the returning light precisely at *a* into an image of *b*. The image of the illuminated retinal point will coincide exactly with the original point of luminosity. The same is still valid, also, when we have to do not with a luminous point, but with a luminous surface or a body, as soon as the eye is adapted for its outlines. All the incident light which is thrown back can always only return to its place of origin, and never can proceed in any other direction.

From this it follows that, without special expedients, we can see nothing of the illuminated portion of the retina, because we cannot bring our eye into the direction of the returning light without at the same time cutting off the incident light absolutely. To our pupil no light from the depths of the other's eye can return which has not proceeded from it [i. e., our pupil]. And as, in general, none at all has proceeded from our pupil, it sees in the darkness of the other's eye merely the reflection of its own blackness; only those portions of the retina become visible to it on which its own dark image is copied.

We have until now assumed that the observed eye furnishes absolutely accurate images. When that is not the case, the propositions heretofore laid down do not hold strictly true, the returning light will indeed proceed to the illuminating body, but it will also in part pass by that, and an observer who approximates himself to the line of direction of the incident light, will be able to perceive a part of the light which is coming out. On this fact are based the methods of Cumming (*Medic. Chirurg. Transactions,* Vol. 29, p. 284) and Brücke (*J. Müllers Archiv.* 1847, p. 225) for observing the illumination of human eyes. From what has been said it is manifest that, in this way, the illumination must be the greater, the less exactly the rays of a luminous point are concentrated on a point of the retina, therefore especially in faulty adaptation. Besides, I have convinced myself that one may observe a weak illumination, according to the method of E. Brücke, even in eyes with good acuity and under perfect adaptation for the luminous body, from which is to be concluded that, under all circumstances, a small quantity of incident light is scattered laterally. The cause thereof may be inexactness of the eye, incomplete transparency of its refracting parts, or diffraction at the border of the pupil.

In any case, the observer perceives, in this experiment, only a small part of the returning light, and indeed precisely that which is irregularly refracted and which cannot be used for the production of a regular image. Some other method is necessary for the attainment of our object, a method which makes it possible to look into the eye not merely somewhat, but exactly, in the direction of the incident light. The expedient for this has already been found in an accidental observation by E. Brücke. v. Erlach, who wore spectacles, saw, indeed, the eyes of an acquaintance shine, when the acquaintance saw reflected in the lenses of the spectacles a light which there was in the room. In this way, therefore, uncovered lenses were employed as illuminating mirrors, and through these very objects the observer looked toward the observed eye. Precisely the same expedient we shall employ for our purpose, replacing, however, the spectacle lenses to advantage by well ground plane glasses.

In a darkened room, where only a single source of light, a well burning lamp or an opening in the window shutter for the sunlight, is present, let one set a small, plane glass plate in such a way that the observed eye may perceive therein the mirrored image of the light, without, however, its necessarily gazing at this mirrored image directly. From out the anterior surface of the lens there falls, by this arrangement, light into the observed eye, and through the same glass at the same time the observer can view the eye, without, while so doing, being in the least aware of any light which is being reflected from its anterior surface. One sees that, in this way, it becomes possible to look into the subject's eye in precisely the same direction as that in which the light falls upon it. Under these circumstances the eye of the observer in fact receives light from out the depths of the other eye, and sees its pupil apparently grow luminous.

In Fig. 1, let A be the flame, C the glass plate, D the observed, G the observing eye. The light from A which falls upon the mirroring plate, is by that partly reflected, and the reflected part continues, according to the laws of catoptrics, as if it proceeded from the reflected image of the flame at B. For the observed eye this mirrored image represents the place of the luminous object, and upon its retina is thrown an inverted and minified image. Moreover, the axis of this eye can be turned in any direction, say toward the object H. According to the already developed rules, the refractive media of D cast the image of its retina and of its retinal images again at B. For B is the apparently present object for the eye D, and the rays returning from D must proceed again to their place of origin. On the way from D to B this light encounters once more the reflecting plate, a part is reflected and returns to the real flame A, another portion passes through the glass and strikes the eye of the observer G.

By this arrangement the pupil of the eye D appears to shine with a red light, and indeed as a rule more strongly than I have seen it do by Brücke's method. According to that method, there contributes to the illumination only the little light which, in the eye, is not completely and regularly refracted; according to the method just described, on the contrary, the entire light, with the exception of the part (to be sure not an inconsiderable part) which is lost by the passage through the reflecting glass. Moreover, the illumination is of very different strengths, when different portions of the retina receive the image of the flame. When the eye D turns in different directions, the clear retinal image must always remain in the prolongation of the line B D, and will therefore fall successively on various portions of the background. If it falls on the place of entrance of the optic nerve, then the most of the light is reflected, the pupil lights up with a strong yellowish white, almost as if the flame stood behind it. The retina proper, on the other hand, reflects less, and indeed red light. In general, the image of the flame upon it appears the brighter, the nearer; the darker, the farther, it lies from the place of entrance of the optic nerve. On the contrary, the place of direct vision, the yellow spot (which is struck when the observed eye D gazes directly at the mirrored image of the flame at B) reflects, by way of exception, very much less light than the parts which are nearest to it, and is therefore the most unfavorable spot for this experiment.

In order to fulfill the condition that the observer gaze into the eye exactly in the direction of the incident light, the glass plate may be directed either by the observed or by the observer. If the former is to do it, let him turn the plate first of all so that he sees therein the mirrored image of the light, then again so that this image appears to him exactly in the same direction as the observing eye, that, in other words, the latter and the mirrored flame cover each other. In this way the required condition is fulfilled. At the same time occurs this inconvenience, that the observed eye must look directly at the flame, the retinal image therefore falling precisely on the spot whence the light is the least reflected. If, however, the observed eye, after it has found the correct position, turns a little sidewise, in order to let the light shine more brightly, then the pupil becomes displaced and the correct position is disturbed. Still, one can then assist the matter by gentle turning of the mirror now this way and now that.

It is better, however, to perform the experiment in another way, whereby the observer holds the glass himself. One must, by this method, shade the face that is being observed, and make the reflecting plate so small that it is barely large enough to see through. The light reflected from it then produces on the shaded face of the observed a small, bright spot, which has about the form of the reflecting glass. This point should be so managed by the observer that its centre falls upon the observed eye, while he himself looks through the glass. In this way the glass may easily be placed correctly, and the observed eye may, without the slightest difficulty, be turned toward all sides in order to cause the image of the flame to fall on different parts of the retina.

Every person can, furthermore, in similar fashion, by the aid of a bit of plane glass, see one of his own eyes grow luminous. He should step before a mirror, set up a lamp at one side, hold the glass before his right eye in such a way that he sees the flame reflected in the plate, and turn the glass so that the image of the flame coincides with the mirrored image of his left eye; then the left eye sees the mirrored image of his right pupil grow luminous, but of course only weakly so, because the retinal image falls on the outer side of the eye at a considerable distance from the optic nerve.

Moreover, the same simple expedient permits itself to be employed with advantage for illumination, in every instance when one wishes to look into a dark cavity with a narrow opening, for example, the auditory meatus, the nose, and so on. In order to view the drum membrane, one should seat the subject of the experiment with his back toward the window, preferably in sunshine, draw the auricle a little downward, and cast the reflected sunlight into the auditory meatus, while one gazes through the glass. In this way one may very easily and permanently illuminate the tympanic membrane as strongly as he wishes, and so observe it.

In order to see the pupil become luminous any simple plate of glass suffices for the mirror; one does not need in that case to pay particular attention to the intensity of the light. Should it be desired, however, by means of this light to recognize distinctly the structure of the retina and the character of the image of the flame, then one must endeavor to make the illumination as strong as possible. That can be done in two ways, namely, by a proper choice of the angle under which the incident light is reflected from the mirroring plane, and by an increase in the number of the reflecting plates. I will now unfold the principles which have guided me in this connection during the construction of my instrument and which would also serve as a basis should oculists think it necessary to produce modifications of the instrument for practical purposes. For those of my readers to whom the physical conceptions involved are not familiar, I remark furthermore that this exposition is not necessary for an understanding of the sections to follow.

From every limiting surface of a glass plate, the more light is reflected the larger the angle of incidence, that is, the angle between the ray and a line which stands vertical to the plate. Since, in the case of reflection from the upper surfaces of transparent bodies, the light waves of different undulatory directions conduct themselves differently, we must think of the incident light as divided into two equal parts, of which the one is polarized parallelly to the reflecting surface, the other vertically thereto. The light-intensity of all the incident light we will call J, therefore that of each of the two divisions mentioned ½ J, the angle of incidence (angle between the incident ray and the incident-perpendicular) a, the angle of refraction (between the refracted ray and the incident-perpendicular) a_1, the index of refraction n. If a is given, we find first of all a_1 by means of the equation

$$\sin. a = n \sin. a_1.$$

The intensity P of the light reflected from a limiting surface between air and glass and polarized vertically to the plane of incidence, is, according to the formula of Fresnel

$$P = \frac{J}{2} \cdot \frac{\text{tang}^2 (a - a_1)}{\text{tang}^2 (a + a_1)}$$

Likewise the intensity Q of the reflected light which is polarized parallelly to the plane of incidence

$$Q = \frac{J}{2} \cdot \frac{\sin^2 (a - a_1)}{\sin^2 (a + a_1)}$$

When several reflecting plates lie parallel, one behind another, and the illuminating surface is sufficiently large for its mirrored images, which are produced by the individual reflecting surfaces, to superimpose themselves, in greatest part, for the observed eye, then the individual images combine into one image of greater brightness. By computation of the quantities of light reflected to and fro between the different surfaces, one is able to determine for every system of parallel surfaces, how much light is, on the whole, reflected. For an indefinite number n of the reflecting surfaces one finds the sum Π of the light polarized vertically upon the plane of incidence

$$\Pi = \frac{n P}{J + 2 (n - 1) P} J$$

and the sum Σ of that which is polarized parallelly to the plane of incidence

$$\Sigma = \frac{n Q}{J + 2 (n - 1) Q} J$$

As I find these formulæ in no writing on physics I give their derivation briefly at the end of this essay.

The sum $\Pi + \Sigma$ gives us the entire quantity of light which is thrown back from the system of reflecting surfaces and which proceeds to the observed eye. We will set it down as equal to H, so that

$$H = \Pi + \Sigma$$

When the width of the pupil remains unchanged, the brightness of the retinal image is proportional to this quantity of light. The quantity of light returning from the eye we may therefore set down as equal to m H, where m designates a coefficient whose value is constant for different light-intensities, though dependent on the nature of the place on the retina from which the light proceeds. The returning light divides at the reflecting surfaces once more into a reflected and a transmitted portion, only the latter arriving in the observer's eye. The light which is reflected at the retina possesses, as is generally the case with diffuse reflected light, no longer any polarization, conducting itself in this respect, therefore, like the light from the light-source as it strikes upon the mirror. Inasmuch as, in addition, it falls upon the plates under the same angle, proportionately as much of it is reflected and transmitted as of the former [the light from the light-source]. If we designate the transmitted part by X, then we have the proportion

$$X : m H = (J - H) : J.$$

From this may be computed the quantity of light X, which passes into the eye of the observer. For $H = 0$ and $H = J$; that is, when no light or all the light is reflected, X will $= 0$. Between these extreme values of H exists a maximum of the value of X, which can be computed according to the known rules of the differential calculus. The maximum occurs when

$$H = \tfrac{1}{2} J.$$

Then will

$$X = \tfrac{1}{4} m J.$$

By this condition is also determined for a given number of reflecting plates the angle under which the reflection must occur in order to give to the observer the brightest image. Unfortunately, the equation which expresses the dependence of the value H on the angle of incidence a, cannot be solved after a; we can therefore find the proper values of a only approximately by means of computational trials. Besides, it is of no use to drive the exactness of this computation very far, first, because the brightness for the observer is not materially altered, even when the position of the glasses is not that requisite for the maximum, and, secondly, because the alterations in the width of the pupil produced by different intensities of the incident light cannot be taken into account.

As the pupil of the observed eye becomes smaller under stronger incident light, the brightness of the retinal image will not increase entirely in the same proportion, when the values of H increase, as they should do according to the developed formulæ. It is therefore more advantageous to re-establish in the instrument the values of H as somewhat smaller than would be requisite for the maximum of H in the foregoing computation. One reaches, for example, the value, which slightly deviates from the foregoing maximum,

$$X = 1/5 \, m J$$

when the light is reflected from one glass plate at an angle of about 70°, from three at an angle of 60°, of four at 55°, and these positions are therefore approximately the most advantageous.

The necessary brightness, therefore, can even be reached with a single glass plate for a mirror. The use of several plates at a smaller incidence-angle has, however, essential advantages if one would attain to distinct images of the retina. First of all, glass plates, even when they have well ground parallel surfaces, are not always internally of so homogeneous a structure as still to yield, by an oblique view, good, distinct images. Then, it is more difficult, by a very oblique view, to give to a reflecting plate the correct position toward the observed eye, and to hold the plate therein. Also, the observer, by the lateral parts of his head, cuts off more easily the rays of light which should fall upon the mirror; especially may this be avoided with difficulty when the angles of incidence are more than 70°. Finally, it remains to be especially considered that a small quantity of the light which falls into the observed eye is in fact reflected from its cornea and appears to the observer as a washed-out light spot in the visual field. This falls over the centre of the pupil, when the observed eye turns straight toward the mirror, therefore when it looks directly at the mirrored image of the flame; it falls more to one side when the observed eye gazes in any other direction, disturbing, however, the observation of the retina always more or less. It is therefore an essential advantage if one can weaken the corneal reflex for the observer to a considerable degree. Now, in fact, that image appears much weaker when 4 plates reflect at 56°, than when 3 reflect at 60° or one at 70°, while the retinal image, as already mentioned, holds to just about the same illumination. That is to say: the apparent brightness of the corneal reflex is not proportional to that of the retinal image, because the light which falls into the observed eye, and which is partly or wholly polarized by reflection, is depolarized by the diffuse reflection at the retina—something which does not occur from the specular reflection at the cornea. If the cornea, of the quantity of light A which falls upon it, reflects the portion μA, then the quantity of light which, in our experiments, passes from the cornea into the eye of the observer, equals, according to the same principles and the same designation as before,

$$\frac{\mu \Pi \left[J - 2\Pi\right] + \mu \Sigma \left[J - 2\Sigma\right]}{J}$$

Computation gives the result already stated. It is therefore from every point of view more advantageous to attain the necessary brightness by increasing the number of the plates, while they reflect the light at the polarization angle of 56°, than by increasing the angle of [illegible] [illegible] the [illegible] [illegible] could be made to disappear [illegible]; [illegible] [illegible] [illegible] [illegible] the [illegible] of the plates.

[illegible] [illegible] [illegible] in the [illegible] [illegible] that the flame of a [illegible] [illegible] [illegible] [illegible] [illegible] is employed as the light-source. [illegible] the [illegible] is properly [illegible] the light of such a lamp [illegible] [illegible] [illegible] [illegible] [illegible] as [illegible] [illegible] to [illegible] or [illegible] the [illegible] [illegible] of the [illegible] of the observed eye. One can therefore [illegible] [illegible] the [illegible] as long as one likes. Only when the eye looks directly at the [illegible] image of the flame will this degree of [illegible] [illegible] [illegible] not long [illegible]. If one has at his disposal a [illegible] [illegible] light for [illegible] [illegible] which falls into a dark room through an opening in the window-shutter, then one can see the picture of the retina [illegible] [illegible] [illegible] after proper weakening of the light, [illegible] it to reflect from a mirroring-plate as vertically as possible than when this takes place obliquely. The quantity of light which one may permit to enter into the eye is limited particularly by the sensitiveness of the latter. If now, one has at his disposal exceedingly strong light, which by every kind of reflection, if it is not at the same time adequately weakened in another way, exceeds this limit, then one however sees the retinal image, which has reached the limit of endurable intensity, at its brightest when as little as possible is lost at the second reflection. That is, however, the case when the light is thrown back from a plate almost vertically. I have not had opportunity to institute such an investigation by means of sunlight; I do not believe, however, that, by that method, any considerable advantages are to be secured, because, in the case of vertical reflection, the apparent brightness of the disturbing corneal reflexes increases at a much higher rate than that of the retinal image.

There was expressed to me a number of times the supposition (at first blush a very plausible one) that by a convex lens which should concentrate toward the observed eye all the light which falls upon it, the quantity of light falling into the eye and therefore also the brightness of the retinal image, could be considerably increased. I will therefore here direct attention to the fact that, in this way, not the brightness but only the size of the retinal image is increased. When we bring the eye to the point of union of the light-rays, which have passed through a lens, then the entire surface of the lens appears to us luminous with that light-intensity which belongs to the luminous point. Instead of the smaller retinal image of the luminous point, there forms itself for us therefore a larger one with the same intensity, that of the lens-surface. Moreover, by no complicated arrangement of lenses can the brightness be increased. In order to perceive this, we need only to remind ourselves of this fact from the theory of telescopes, that through no telescope or similar arrangement of lenses can an object of appreciable diameter appear brighter than with the naked eye. As, now, the inhabitant of the seeing eye subjectively perceives the surface no brighter through the lenses, so can, objectively, the image in his eye by the use of no sort of lenses be brighter than without them. For to an objectively brighter retinal image there must always correspond a stronger subjective light-perception.

2. Production of a Distinct Image of the Retina.

We now come to investigate how, by means of the light which, returning from the retina of the observed eye, falls into the eye of the observer, we may be able to receive distinct images of the retina itself, and of the picture of the light-source cast upon it. For this purpose let us take again our Fig. 1. According to the explanations just made, the ocular media will so refract the rays returning from points of the retina of the eye D, that they come together outside the eye and indeed in the corresponding points of the image B. The image which the ocular media cast of the retina and of the retinal image of the flame, coincides therefore in size and position with the first reflected image of the flame. An observer who (reckoning outward from the mirror) stands on the other side of B and at the distance of distinct vision from B, would therefore in fact be able to see that image of retinal objects distinctly. His visual field, however, limited by the pupil of the observed eye, would, at the comparatively considerable distance of the two eyes from one another, be so small that it would be impossible to combine the viewed details into a complete picture.

The regard which we must pay to the enlargement of the visual field, makes it much more necessary to approximate the two eyes as closely to each other as possible. Then, however, the image B falls in general behind the back of the observer, and can not be plainly seen by him. If, for example, in Fig. 1, the observing eye is at G, then it receives the light rays which proceed out of the eye D and which come together at the points of B. Now a normal eye can indeed unite upon its retina parallel rays, as these move from infinity, and divergent, as these come from nearer points, but not convergent rays. The simplest way to assist in this matter, and to make the convergent bundles of rays divergent, is a concave lens, which is [illegible] Fig. [illegible]

[illegible] the [illegible] distance [illegible] distance [illegible] of an [illegible] is smaller [illegible] does [illegible] imperfect [illegible] which [illegible] and [illegible] glasses. [illegible] glass of a [illegible] Galilean [illegible]

If the accommodation distances of the two eyes [illegible] and [illegible] are given, and in addition the mutual distance of the eyes and the concave glass are placed according to the principles above set forth, that [illegible] then is the focal distance which is to be given to the concave glass to be determined according to the [illegible] of refraction in lenses. This is found to equal

$$\frac{\text{[illegible]}}{\text{[illegible]}}$$

or

$$\frac{(\text{[illegible]} - \text{[illegible]})(\text{[illegible]} - \text{[illegible]})}{\text{[illegible]} - \text{[illegible]} - \text{[illegible]}}$$

The greater are the accommodation distances [illegible] and BD, the greater must also be the focal distance of F. The observer will, therefore, if one of the two eyes is short-sighted, employ stronger concave glasses, and if one eye is far-sighted, weaker ones, than for two normal eyes. When the observing and the observed eye exchange their roles, without altering the condition of their accommodation, there will generally become necessary a glass of a different focal distance, and indeed as [illegible] < [illegible] a weaker one, when the more short-sighted eye observes than when it is observed. Still a closer consideration of the foregoing formula shows that this difference is relatively slight in the case of not too short-sighted eyes, so that, in the case of such, the same glass can serve for mutual observation.

The magnification is determined according to the known laws of optics in this way, that the image E, viewed from the center of the lens F, must appear under the same visual angle as B, its imaginary object. Since the eye G, the lens F and the eye D stand as closely together as possible, then will B appear from F only a little larger than from D. The eye G therefore sees the retinal image of the flame magnified, and indeed just as large, or, considered exactly, a trifle larger, than the eye D sees the original flame. The parts of the retina on which the image of the flame falls, appear likewise in the image E again, magnified of course in the same proportion as that.

According to what has just been said, the proportion of this enlargement is equal to that of the retinal image to its object. Let us take as the distance of the decussation-point of the refracted rays from the retina, according to Volkmann's measurings, 4 lines, for the distance of the object from the eye the normal visual distance of 8 inches, then the magnification is found to be 24 times.

We have compared the ocular media in our experiment with the objective of a microscope, the concave glass with the ocular. Now, in place of the latter, one should be able to produce a combination of two convex lenses, which stand at a distance from one another of less than the sum of their focal distances, as is the case in the ordinary compound microscope. The first of the lenses would, like the collective glass of this instrument, unite the weakly converging light-rays which proceed from the observed eye, more promptly to an image, which, situated between the lens and its focal distance, would exhibit the flame-image upright, the retina inverted. This image could then be seen magnified by the second convex lens. I have debated the results of such a combination, according to the known laws of optical instruments, with respect to magnification, illumination, visual field, etc. As the computation showed that in this way no essential advantages were to be secured, as compared with the simple concave lenses, it will here suffice to adduce those results very briefly. It is hereby presupposed that the first lens, so far as the mirror permits, is approximated to the observed eye, and that the observing eye lies close to the second lens.

First of all, as to the illumination, the maximum thereof is directly attained by a concave lens for the middle of the visual field. If the same thing is to occur by two convex lenses, then these must be so chosen and arranged that no other enlargement takes place than by the concave lens, that is, in such a way that the magnified retinal image of the flame appears to the observing eye under the same visual angle as the inverted image of the flame does in the eye that is being observed.

If this enlargement is to occur, the image from the first lens must fall, as in the ordinary ocular tubes of the compound microscope, in the middle between both lenses. In the case of a weaker magnification, it is possible to cause a larger portion of the visual field to appear in the maximum of brightness; in the case of stronger, on the contrary, that can no longer occur even in the middle. As advantageous, therefore, as even a stronger magnification might be, still such a one is not practicable, because the illumination would thereby suffer too much, and a living eye would not well endure for a longer time without damage the incidence of still stronger light than that reflected from a good lamp. Then, too, is the fact that the living eye cannot be thoroughly fastened, as would be necessary for the fixation of individual parts of the image in the case of stronger magnification.

Next to be considered is the visual field. The part of the retina which one can survey is always the smaller the further one removes oneself from the observed eye; the larger the nearer one comes to it. The limit of approximation is, however, set in this way: that the obliquely placed mirror-glasses have to be inserted between the eye and the glass-lenses.

In order to compare by means of computation the effects of various lenses, we must therefore accept as equally great the distance of the concave glass and that of the first convex glass from the observed eye. If then at the same time the condition is observed, that the brightness in the middle of the visual field should reach its maximum, then are found definite focal distances of the convex lenses for every given distance from the eye, which make the visual field at its largest. If one choose the focal distances of both the convex lenses in accordance with these determinations, then it further appears that when the distance of the lens from the eye is smaller than the focal distance which one may give to the objective of a telescope from the aperture of the pupil without prejudicing the distinctness of the image, therefore in the case of achromatic lenses smaller than perhaps the tenfold pupillary diameter, the concave lens, if larger, the convex lenses can give a larger visual field.* Now, in the case of the closest possible approximation of the lenses to the observed eye, the distance between both will of course, on account of the mirror being placed in the

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* The sentence, in the original, is hopelessly obscure; it is, therefore, also obscure in the translation. The reader should recall the fact that Helmholtz, at the time when he wrote the "*Beschreibung*," was not yet master of a literary style, and I have deemed it far the fairer way not to force into the sentence a meaning of my own.—(T. H. S.)

interval between the lenses, remain in general somewhat larger than the tenfold pupillary diameter, and one would therefore be able to secure by means of two convex lenses a slight advantage for the visual field. Inasmuch, however, as the lenses, in order to yield this advantage, must have focal distances of 36 to 40 lines, it may become very difficult to receive an image of the same distinctness as by a concave lens which may have a focal distance of 8 to 10 inches. I, at least, have not been successful in this matter, by the combination of such convex lenses as stood at my disposal. Moreover, it transpired, in the experiments with such lenses, that the correct location of the instrument for the perception of the retinal image is both found and kept with much greater difficulty. With a simple concave lens it is, to wit, not necessary that the axis of the lens be directed exactly upon the observed eye, if only the mirror casts light into it. This condition, however, must be observed in the case of two convex lenses.

Consequently it appears to be more advantageous to retain the simple concave lens as ocular, while one almost everywhere else in optics replaces it to decided advantage by convex lenses. A decided advantage of the latter occurs, to be sure, even in our case, which would make their employment desirable, to wit, the advantage that, by an altered distance of the lenses from each other, one can adjust the apparatus to all visual distances of the observed and the observing eye, while, for this purpose, one must exchange the concave lens for another. If one could completely make fast the head of the observed person and the instrument, convex lenses would in consequence be more convenient; without such arrangements, however, all their other advantages are outweighed by the disadvantage of the difficult placing of the instrument. I have therefore myself always employed only a simple concave lens.

3. Description of the Ophthalmoscope.

In order to institute observations of the kind described, it is convenient to unite the mirror-plates and the concave lens by means of a suitable frame. I propose for such a combination the name *Augenspiegel,* by analogy with similar instruments. The instrument is viewed in Fig. 2 from in front, in Fig. 3 exhibited in horizontal cross-section. The reflecting plates hh are fastened, by means of the brass piece gg, to the circular plate aa, at an angle which is equal to the chosen angle of incidence of the light rays—in the figure, 56°. The brass piece gg forms with the glass plates a hollow, right-angularly triangular prism. In Fig. 3 one sees into the inner cavity thereof, and has before him one of the right-angularly triangular basal surfaces. Of the three quadrangular lateral surfaces of the prism, that which corresponds to the hypothenuse of the basal surface, is formed by the glass plates, that which corresponds to the longer cathetus stands free, that corresponding to the shorter cathetus lies on the disc aa, and carries a cylindrical process p, which, by means of a corresponding circular opening in the plate aa, so clasps through, that it holds the prism fast against the plate, but permits a turning on its axis. The glass plates are held against the prismatic brass piece by the frames kkkk, whose over-reaching lateral edges are secured to the brass piece gg by the screws ll. The disc aa rests on the cylinder bbcc without being permanently fastened to it. In the border of aa, namely, there are cut four openings of the form f, to which openings there correspond four screws ee with cylindrical heads and thin necks, inserted into the border of the cylindrical ring bb. In Fig. 2 are shown only two of these screws, in order to let the holes f be seen. The heads of the screws allow of their shoving through the broad circular portions of the openings, and if then the disc aa is turned about its center, the necks of the screws pass into the smaller, slit-shaped part of the same opening, while their heads lap over and fasten the disc to the ring bb. In that way it is possible to remove the disc very easily and quickly from the setting of the concave lens, and to exchange the lens for another. The concave lens nn lies between the plate aa and the floor of the cylindrical piece dd, which is screwed into bbcc and can be set back by screwing round, when it becomes necessary to lay two lenses one upon the other for very short-sighted eyes. The whole is fastened to the handle m. For a normal-eyed observer, the numbers 6 to 12 of the ordinary concave spectacle lenses, are sufficient for the adjustment to all adaptational conditions of the eyes to be investigated. For the viewing of other normal eyes, I generally employed Nr. 10. For very short-sighted eyes, two lenses should be superimposed.

As to the reflecting plates, those of ordinary mirror-glass are not appropriate, because their two surfaces are as a rule not sufficiently parallel to cause the images which they cast of the lamp-flame to coincide in the way that they should. The glasses must therefore for our use be especially ground, in order to receive parallel surfaces, though this condition need not be fulfilled with such exactness as in the case of the plane-parallel glasses which one employs in the finer measuring instruments.

A good blackening of the non-reflecting surfaces is essential. Since of the bright light which falls upon the instrument, only a proportionately small part returns from the retina of the observed eye, all the remaining remnants of the light, which might perhaps get into the eye of the observer, must be done away with. First of all, the inner surface of the ocular piece dd must be blackened, and the observer must place his eye as closely into it as possible, in order to cut off all the light which could fall from the flame upon this surface. Secondly, the outer surface of the disc aa and of the prismatic mirror-frame kkkk must be blackened, in order that blank metal surfaces, which are turned toward the observed eye, may not produce disturbing corneal reflexes. Thirdly, however, the inner surface of the mirror-frame is to be blackened with especial care. The light of the flame which falls on the reflecting plate, passes in greater part through, and strikes the plate gg. All that is not here absorbed, returns to the mirror, is reflected from this in the same direction to the observing eye, in which the weak light from the retina of the observed eye arrives, and mingles with the image of this membrane. I have found, in this matter, the general methods of procedure of mechanics for blackening brass-pieces to be inadequate, and the framework of the mirror must be tapestried internally with black velvet, which absorbs the light more completely.[*]

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[*] The subsequent history of the ophthalmoscope "down to a time within the memory of men still living," is, very briefly, as follows: Ruete, in 1852, invented the "indirect method" *(D. Augenspiegel u. d. Optometer,* Göttingen, 1852). He employed a concave perforated mirror, held at a considerable distance from the observed eye, and between the mirror and the eye one (sometimes two) spherical convex lenses. Helmholtz, also, had made use of convex lenses, but these he had placed *behind* the mirror, finding them there, of course, of very little value (see herein).

Helmholtz, next, explained most thoroughly *(Vierordt's Archiv,* 1852, p. 827) the method which Ruete had invented. In the very same paper Helmholtz described what he called "the simplest method," by which an eye could be examined by means of only a candle, a screen and a convex spherical lens. He also mentioned (still in the same most memorable article) the so-called Rekoss discs—i. e., two rotatory discs, each containing four concave lenses inserted not far from the peripheries of the discs. One of the discs held lenses from 6 in. to 9 in. focus, the other those from 10 to 13 in. The Rekoss disc, or discs, with numerous modifications, is, as all are aware, in use at the present day. Rekoss was not an ophthalmologist, but an instrument-maker of Konigsberg (where Helmholtz at the time was living).

Coccius, in 1853, invented an instrument which found much favor for years. It consisted of a lens, set in a frame, in front of a plane mirror. The distance between the mirror and the lens could be altered very considerably.

Eduard Jaeger, in 1854, produced a combination of the Helmholtz and the Ruete instrument—that is to say, the plates of silvered glass in the Helmholtz instrument were made replaceable by a concave silvered mirror, such mirror to be used for the indirect method. To this affair of Jaeger's, Strawbridge, of Philadelphia, in 1871, added three interchangeable Rekoss discs.

The ophthalmoscope of Liebreich is too familiar to all to require the slightest description. So, almost, is that of Loring, with its single disc and double row of lenses, the disc being movable up and down for the purpose of bringing into action either the one row or the other. Wadsworth, of Boston, invented the

When one desires to use the instrument, he sets the person to be examined in a dark room and next the corner of a table on which, at a level with the eye and sidewise from the face, stands a well-burning, double-draught lamp. It is convenient to set upon the table, at a fitting visual distance, some not too bright object, whereon one can point out to the observed eye certain points for fixation, for example a blackboard divided into squares, each of which is designated by a number, while one causes the eye to fix various points one after another. The image of the flame falls ever on different parts of the retina, which the observer, therefore, may investigate one after another in any order desired. Between the flame and the observed eye an opaque screen must be erected, in order to shade the eye, so that directly incident flame-light may not produce a very disturbing corneal reflex and a narrowing of the pupil. Still, the border of the shadow must pass very close before the observed eye, in order that the ophthalmoscope, which must itself remain in the light, may be carried toward that eye as closely as possible. The observer seats himself before the observed, brings the ophthalmoscope, without at first looking through it, into about the right position, when its reflecting surface casts a bright light upon the face. When one has so turned the mirror that the middle of its light falls upon the eye, and the axis of the instrument is directed precisely into it, one looks through. A person then has, as a rule, at once before him the bright image of the flame, or finds it after more or less moving about. Moreover, one can also, looking through the instrument, discern, to a certain extent, the eye and the clear light which must fall upon it, even if indistinctly and as if they were faded, and also, in that manner, with the help of these [the eye and the light upon it] discover the correct position. If, though the pupil appears luminous, one cannot see the various parts of the retina distinctly, then one must insert another concave lens. An observer who has accustomed himself to alter at will the adaptation of his eye, easily discovers whether he sees more plainly by a far-sighted or a near-sighted adaptation, and whether, accordingly, he must choose more or less strongly curved lenses. Moreover, many persons make the matter difficult, especially those who are not accustomed to looking through optical instruments, and short-sighted persons who see through them with difficulty, insomuch as they involuntarily adapt the eye for great nearness, because they think of the

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"mirror obliquely set," which enables the observer today to look straight through the lenses instead of at an angle. Both the Loring and the Wadsworth instruments are especially valuable for refraction purposes.

The electric light ophthalmoscopes are in the hands of every practising ophthalmologist at the present day, and require no description.

object to be seen as being very close. In that way the eyes of the observer are greatly fatigued, and readily begin to be injected and to water. It is necessary here, as in the case of all optical instruments possessing an alterable adaptation, to adjust the eye for the distance, and then to adjust the instrument to the eye.

After a little practice it is not difficult to find the right lens and the correct position of the instrument. Also, one can easily, on his own eye, show these matters to anyone who has never yet seen them, in order first to render him familiar with the appearance of what he is going to look for. In that way it will be made much easier for him to discover independently the very same things in the eyes of others. Let the instructor, for this purpose, first of all discover the particular lens through which he can see the student's retina plainly, and then let him place this in the ophthalmoscope; then through the same glass the student can see distinctly into the eye of the teacher, if neither of the two is very short-sighted. In the latter case (as explained already) the more short-sighted person needs a somewhat weaker glass when he observes than when he is observed. Let the instructor, then, bring one of his own eyes into the position which has been described as that for the eye to be observed, and let him so hold the ophthalmoscope before him that he may be able, at the same time, to look through its central openings and glimpse the mirrored image of the flame in the mirror, hand over to the student the instrument in this position, and let him look through it. The student will then see in the eye the image of the flame. In order to teach him to recognize the appearance of the parts of the retina, let the teacher throw the image of the flame on the place of entrance of the optic nerve, because in that place the largest and most recognizable vascular trunks exhibit themselves. Let him, for this purpose, turn the eye gradually more and more to the inner side of the mirrored image of the flame, until this suddenly becomes smaller to him, or disappears. That happens, as is known, when the image falls upon the place of entrance of the optic nerve. Besides, most persons more easily succeed in seeing and recognizing the image of the flame than the tiny parts of the retina in the bright ground thereof.

4. VIEWING THE RETINA AND THE IMAGE OF THE FLAME.

Should one desire to investigate the retina completely, then it is convenient, as already mentioned, to set up a blackboard covered with numbers as a visual point for the eye to be investigated. As soon as this eye fixes one of the numbers, looking past the mirror a little to the inward side thereof, the observer will almost always recognize in the visual field one or two of the larger vessels. He causes the eye to turn to one of the near-lying figures, and notices whether he is brought nearer to the origin or to the branching of the vessels. While, in this way, he traces the vessels in the direction of their larger trunks, he comes at length to the place of entrance of the optic nerve. This distinguishes itself from the rest of the eye-ground by its white color, for it is not covered with pigment and a fine vascular network, but here the white cross-section of the nerve lies wholly free, at the very most shot through by tiny, isolated vessels. Mostly to the inner side, near by, the arteries and veins of the retina press forward from the depths. At times one sees a portion of the vessel still hiding in the substance of the nerve, and understands that, in the living, this substance is decidedly transparent. One distinguishes the two kinds of vessels from each other by the brighter color of the blood and the double contours of the walls in the arteries and in their first ramifications. I have not been able to recognize pulsations with certainty. The first main branches of the vessels border the optic nerve at its inner side, in order to spread out later, above and below, across the retinal field. The appearance of the sharply pencilled red vessels on the clear white ground is of surprising elegance. Somewhat farther to the inner side, close by the nerve, I have always remarked a small, sickle-shaped stripe of shadow, which appears to take its origin from a fold of the retina.

In the other parts, the ground of the eye looks reddish, and indeed first of all round about the optic nerve of a somewhat clear, light-red, the darker, on the contrary, the farther you pass from that place. One sees here larger and smaller branching blood-red vessels, which stand out plainly from the back-ground. The ground itself appears to be not entirely homogeneous, but indistinctly reddish. This would seem to arise from the fact that the close capillary net is too fine, too weakly illuminated and too transparent to be distinguished plainly from the underlying weakly, light-gray substance of the retina. That the ground looks brighter in the vicinity of the optic nerve is no doubt owing to the fact that the retina here, on account of the superimposed fibres of the optic nerve, is thicker, while, toward its periphery, it becomes continually thinner. Moreover, the place of direct vision (the yellow spot) is essentially distinguished in appearance from the parts which lie immediately about it. In order to get this point before oneself, one causes the eye which is being observed to look directly at the mirrored image of the flame. The retina then appears much darker, grayish-yellow without intermixture of red; and one sees no traces of capillary vessels. Then, too, one is greatly annoyed while gazing on the yellow spot, by the tiny image from the cornea, which obtrudes itself precisely in the center of the visual field, while, during the observation of the lateral portions of the retina, it lies to one side.

After deciding what, in the healthy eye, can be made out concerning the nature of the retina, I have no doubt that one will be able to recognize all such disease conditions as permit of recognition by the sense of sight in other transparent parts—for example, the cornea. Increased repletion of the vessels and vascular varicosities must prove easy to make out. Exudates into the substance of the retina, or between that structure and the pigment membrane, must yield themselves to observation, very much as affections of the cornea do, by their brightness against a dark ground. If they lie in part before the retina, they will then enclose its vessels in a veil. I here recall that, according to Brücke, the recent retina is just about as transparent as the other ocular media, and that, apart from its vessels, it is only visible in our experiments because it is strongly illuminated on the deep-black ground of the pigment membrane. Fibrinous exudates, which are nearly always less transparent than the ocular media, must also for that reason, when they lie in the fundus of the eye, considerably strengthen the reflex. Then too I believe that opacities of the vitreous body will be much more easily and certainly recognizable, partly by the illumination of a reflecting glass-plate, partly by the ophthalmoscope. One will even be able to determine with ease, from the indistinctness of the image of the flame and of the retinal vessels, the degree of the opacity. If, in the case of such an opacity, scintillating particles have detached themselves, then too a person will be able to take note of these. In brief, I believe that I may hold the expectation not to be exaggerated, that all the alterations of the vitreous body and of the retina which, until now, have been found in cadavers, will also permit of recognition in the living eye—a possibility which appears to promise the most remarkable advances for the hitherto undeveloped pathology of this structure.*

Finally, it is of interest, for certain physiological purposes, to investigate the accuracy with which the eye forms images. It is best to employ for this purpose a thread, which one draws along horizon-

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*Probably the most significant sentence ever penned by an ophthalmologist. How gloriously the great man's prophecy has been fulfilled is known not merely to specialists and general practitioners, but even, in some degree, to first year medical students and the educated portion of the laity. In fact, there are just two kinds of ophthalmology, that which came before and that which followed after Helmholtz's "*Beschreibung eines Augenspiegels.*"—(T. H. S.)

tally before the flame. Its image remains single, while vertical threads are manifolded by the manifold reflections.

First of all one gets an opportunity to convince oneself, by the appearance of the image, that the different adaptations of the eye really depend upon alterations in the refractive media. One should cause to be fixed an object which is just about as far removed from the observed eye as the thread is from the flame. The observer then sees the elements of the retina and the image of the thread distinctly at the same time. Should the thread be carried nearer to or farther from the eye, then it becomes indistinct in the retinal image, or entirely disappears, while the parts of the retina remain sharp. One perceives from this that the retinal images of objects which stand at various distances from the eye, are in fact not equally distinct. Then again, one should so place the thread that it appears distinct in the retinal image at the same time with the vessels, and should cause the observed eye to fix a point which is either much farther or much nearer than that upon which it was formerly directed. Immediately one sees the retina and the image of the flame become gradually indistinct.

It should incidentally be remarked that, on the white surface of the optic nerve no image is cast, even when the image appears absolutely sharp on the immediately surrounding portions of the retina. Inasmuch as the observer, in the case of a person over whose optic nerve cross-section little vessels run, sees these quite as plainly as those of the retina adjacent, therefore that indistinctness of the image of the flame cannot proceed from the passage of the end of the optic nerve out of the level of the retina. I believe rather that one must regard the transparent condition of the optic nerve mass as the real cause.

Moreover, one is able, whenever it becomes necessary, to convince oneself readily in an objective manner of the presence and the degree of the short- or far-sightedness of the observed eye. Let the observer first investigate a normal eye, which he causes to fix objects at various distances, and notice what concave lenses he is obliged to use in the various stages of adaptation of the eye. In the investigation of any other eye, he then learns from the number of the concave glass through which he saw the retina distinctly the corresponding adaptational distance of the observed eye. The observer is, by this method, entirely independent of the assertions of the other person, for he himself sees, as it were with that other's eye, at least by means of its refractive media. In this way, for example, I was able to convince myself in a completely amaurotic eye, that that eye was simultaneously in a high degree short-sighted. In that way was decided in this case a question of great importance for the anamnesis, whether, that is, certain earlier difficulties of sight recounted by the patient, should be referred to shortsightedness or to commencing amblyopia.

An important physiological conclusion thrust itself upon me in these investigations. The free-lying cross-section of the optic nerve is apparently so transparent that the light which falls upon it must penetrate deeply into the mass of the fibres, inasmuch as, now and then, one sees the bendings of the central artery and vein shimmering forward through the substance of the nerve. When the little image of the flame falls on the place of entrance of the nerve, then all its fibres, or at least a very large part of them, are struck by more or less intense light, and yet, obviously, they perceive no light. If they did perceive it, then that entire portion of the visual field which corresponds to them would have to appear illuminated. Not only, however, is that not the case, but there is even less light perceived than when the image falls upon some other portion of the retina. We must from this conclude that the fibres of the optic nerve are incapable of being affected by objective light (ethereal vibrations), while, nevertheless, they perceive every other kind of irritation as subjective light. This is a paradox, which, of course, has its ground in the ambiguity of the word "light," and is far removed from being an actual contradiction. The vibrations of the ether which we call light, produce, like every other mechanical or electrical irritation, when they strike the retina, the sensation which we call light. But from this, that the retina, protected from pressure and electrical currents and exposed to the action of ethereal vibrations, is much oftener struck and excited by the former than by the latter, it by no means follows that light must be regarded as an especially adequate irritant for the retina and the elements of the optic nerve and as standing in contrast to all the other kinds of irritation. There are no difficulties in supposing that all the irritations which are able to affect the optic nerve system produce sensations of light, that, however, the ethereal vibrations are able to act only on the retina. A similar state of affairs is found in the case of the nerves of touch, with respect to heat and cold. Here too the peripheral expansions behave differently from the trunks. For the latter, slight variations in temperature are no irritant at all, as it appears, and the greater variations, which are able to irritate, produce no temperatural sensations. Besides, one is able to conclude still further that, in the retina, not the fibres, which spread out in a radiating manner from the optic nerve, but the spherical elements, are sensitive to light. Were it the former, then must light which strikes on any place in the retina be perceived by all those fibres which in part end in this place, and in part pass across it on their way toward the retinal periphery. There would therefore extend, in the visual field, from every illuminated point, a bright shine toward the borders of the field, which is not the case. We may accordingly further conclude that even the continuations of the optic nerve fibres in the retina are insensitive to light. There remain only the ganglionic bodies and the nuclear-like structures of the retina, in which the ethereal oscillations are able to act as an irritant.

APPENDIX.

Derivation of the formula for the quantity of light which is reflected from several glass plates.

Whether this formula is correct for n reflecting surfaces is shown by the fact that it is also correct for $(n+1)$. As it also proves right for $n = 1$ and $n = 2$, it must do the same for any desired value of n.

Let the quantity of light which at the given angle of incidence is thrown back by a reflecting surface, when the quantity 1 passes off of light polarized vertically against the plane of incidence, be p, that thrown back by n such surfaces $P_{(n)}$, that thrown back by $(n+1)$, $P_{(n+1)}$. It is demonstrable that if

$$P_{(n)} = \frac{np}{1 + (n - 1p)} \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad 1)$$

then also that equation is correct which arises from this by the substitution of $n + 1$ for n:

$$P_{(n+1)} = \frac{(n+1)p}{1 + np} \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad 2)$$

For the sake of a better designation, let us assume that the system of n reflecting plates lies horizontal and that light falls on it from above. Let the $(n+1)$ th surface be added to the system below. The quantity of light which passes downward from the lowermost nth surface of the compound system to the $(n+1)$ th surface let us call x; that which, reflected from the $(n+1)$ th surface, mounts to the system of the n surfaces, y. The quantity x is composed partly of the portion of the incident light which has passed through the system of n surfaces, partly of the portion of y which is reflected from this system. Therefore is

$$x = 1 - P_{(n)} + yP_{(n)} \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad 3)$$

The quantity y originates from that part of x which is reflected from the $(n+1)$th surface. It is therefore

$$y = xp \quad \dots\dots\dots \quad 4)$$

The quantity $P_{(n+1)}$ which passes upward from the uppermost surface, proceeds in part from that portion of the incident light which is reflected from the system of n surfaces, partly from that portion of y which passes through this system. It is therefore

$$P_{(n+1)} = P_{(n)} + y\ (1 - P_{(n)}) \quad \dots\dots\dots \quad 5)$$

If one eliminates x and y from equations 3, 4 and 5, one gets

$$P_{(n+1)} = P_{(n)} + \frac{p[1 - P_{(n)}]^2}{1 - pP_{(n)}} \quad \dots\dots\dots \quad 6)$$

If we place in this equation 6 the value of $P_{(n)}$ from equation 1, we get in fact, after the necessary reductions, equation 2, whose correctness was to be proved.

For *one* reflecting surface is

$$P_{(1)} = p$$

Equation one (to be tested) gives the same value.

For *two* reflecting surfaces we get the value $P_{(2)}$ without employing equations 1 or 2, if, in the derivation of equation 6, we suppose that $n = 1$ and ${}_{(n)}P = p$. Equation 6 then becomes

$$P_{(2)} = p + \frac{p(1-p)^2}{1-p^2} = \frac{2p}{1+p}$$

Equation 1 gives the same value.

As the latter accordingly is correct for $n = 1$ and for $n = 2$, then it follows from the proof adduced, that it is correct also for $n = 3$, and if it is correct for $n = 3$, that it also is correct for $n = 4$, and so on to infinity.

In a precisely similar way the matter proceeds in the case of light polarized parallel to the surface of incidence.

If we assume the quantity of incident light to be equal to ½ J, and that $p = \frac{2P,}{J}$ and designate that which we have here called P with II, we get the formula in question.